

J/ψ AND ψ' SUPPRESSION IN HADRONIC MATTER

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Abstract

We present a microscopic calculation of the breakup cross sections of J/ψ and ψ' on pions and nucleons as a function of the kinetic energy. These cross sections are used for the investigation of the J/ψ to continuum and $\psi'/J/\psi$ ratios in ultrarelativistic heavy ion collisions. The contribution of produced comoving pions to the $\psi'/J/\psi$ signal is calculated. While this model can account for the data, the uncertainties in the parameter values do not allow to exclude the possibility of additional sources for charmonium absorption, like a resonance gas or the quark gluon plasma.

Keywords

heavy-ion collisions; quark potential model; hadron-hadron interaction; J/ψ suppression

Charmonium states are possible probes for dense matter formation in the early phase of ultrarelativistic heavy ion collisions. The measurement of the J/ψ signal was proposed as a test for deconfined matter (Matsui and Satz, 1986). However, it has been shown that the J/ψ yield is affected by many processes, which obscure the data analysis. The ψ' to J/ψ ratio seems to give a much clearer signal, since the production process is the same for both particles.

We consider the absorption of J/ψ and ψ' mesons by dissociation on hadrons in a microscopic approach. The quark potential model is used for the description of hadron–hadron interactions, for more details see (Barnes and Swanson 1992, Martins *et al.* 1995). Mesons are described as quark-antiquark bound states. The interaction Hamiltonian H^I between a quark and antiquark is given by a Coulomb-like term and the spin-spin interaction that arise from one-gluon exchange. An additional term H^{np} accounts for the nonperturbative nature of strong interaction at low energies. The parameters of our model are fitted to the mass spectrum of the relevant hadrons ($\pi, \rho, D, D^*, J/\psi, \psi', p, \Lambda_c, \Sigma_c$). The charmonium dissociation can be understood as a quark rearrangement process of the form $(Q\bar{Q}) + (q\bar{q}) \rightarrow (Q\bar{q}) + (q\bar{Q})$ for dissociation on light mesons and $(Q\bar{Q}) + (qd) \rightarrow (Qd) + (q\bar{Q})$ for dissociation on nucleons where Q, q represent a heavy and light quark respectively and d a diquark. We calculate the transition matrix element from initial state (hadrons A and B) to the final state (hadrons C and D) as the sum over all possible quark exchange subprocesses between the hadrons, restricting ourselves to Born approximation. The resulting cross sections are shown in Fig. 1, where only the final channels with lowest thresholds are included. The reaction probability is enhanced near the reaction threshold. In addition to the threshold behaviour, the asymptotic cross sections at very high energies can be calculated from only the perturbative part of H^I . In the intermediate energy range, the behaviour is interpolated between both limiting cases. The ψ' has a lower reaction threshold and a higher peak value than the J/ψ and therefore it is stronger absorbed in hadronic matter.

pA data (Alde *et al.*, 1991) show a $\psi'/J/\psi$ ratio which is nearly independent of the mass

number A . A charmonium nucleus absorption cross section of 4.5 mb for both J/ψ and ψ' is capable to reproduce the data. Due to finite formation times for the ψ states, they are formed far outside the nucleus. The color singlet absorption of such a small expanding $Q\bar{Q}$ state is not sufficiently large to account for the nucleonic absorption. One has to conclude that there is another absorption mechanism, which might be the color octet interaction of the $Q\bar{Q}$ with nucleons.

A quantitative investigation of the measured suppression ratio (Ramos, 1995) has been done recently in a the row on row model of the nucleus–nucleus scattering (Wong, 1995). It has been shown, that the same ψ'/ψ ratio in S-U collisions can be obtained with an absorption on soft gluons, on produced comoving hadrons or in a mixed scenario. The cross section at a given impact parameter b is given by

$$\frac{d\sigma_{\psi}^{AB}(\mathbf{b})}{\sigma_{\psi}^{NN} d\mathbf{b}} = \int \frac{d\mathbf{b}_A}{(\sigma_{abs}^{\psi N})^2} \left\{ 1 - \left[1 - T_A(\mathbf{b}_A) \sigma_{abs}^{\psi N} \right]^A \right\} \left\{ 1 - \left[1 - T_B(\mathbf{b} - \mathbf{b}_A) \sigma_{abs}^{\psi N} \right]^B \right\} F_{co}(\mathbf{b}, \mathbf{b}_A) \quad (1)$$

$$F_{co}(\mathbf{b}, \mathbf{b}_A) = \frac{1}{N_< N_>} \sum_{n=1}^{N_<} a_n \sum_{i=1}^n \exp \left[\int_{t_0(n)}^{t_f} dt \frac{1}{\tau_{\psi}(t)} \right]. \quad (2)$$

$N_<$ and $N_>$ are the smaller and larger number of nucleons in the colliding rows at transversal location $\mathbf{b} + \mathbf{b}_A$, T_A and T_B are the thickness functions of the nuclei and n is the number of volume elements with n collisions inside. The comover absorption F_{co} is mainly determined by the ψ relaxation time t_{ψ} . An analog equation holds for the ψ' cross section. Assuming a constant life time, we calculate t_{ψ} from the absorption cross sections with a surrounding of thermal pions at 200 and 250 MeV temperature.

The results for the contribution of secondary pions to the J/ψ absorption in A-B collisions provide a good description of the data. Using the same parameters, we perform the same calculation for the ψ'/ψ ratio. This ratio is more sensitive to the interaction of the quarkonium state with comoving matter since the influence of nucleons almost cancels in this ratio.

Our result is shown in Fig. 2. At lower temperatures the ψ'/ψ ratio becomes larger. For a

reasonable temperature of 200 MeV, there is room for an additional absorption mechanism. However, this are not necessarily hints for an evidence of a quark gluon plasma, ρ resonances and other correlated matter states are also capable to dissolve the charmonium states because of the low reaction threshold for these processes. Some more detailed investigation has to be done in order to understand the true nature of charmonium suppression before one can conclude the evidence of a quark gluon plasma phase.

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FIGURES

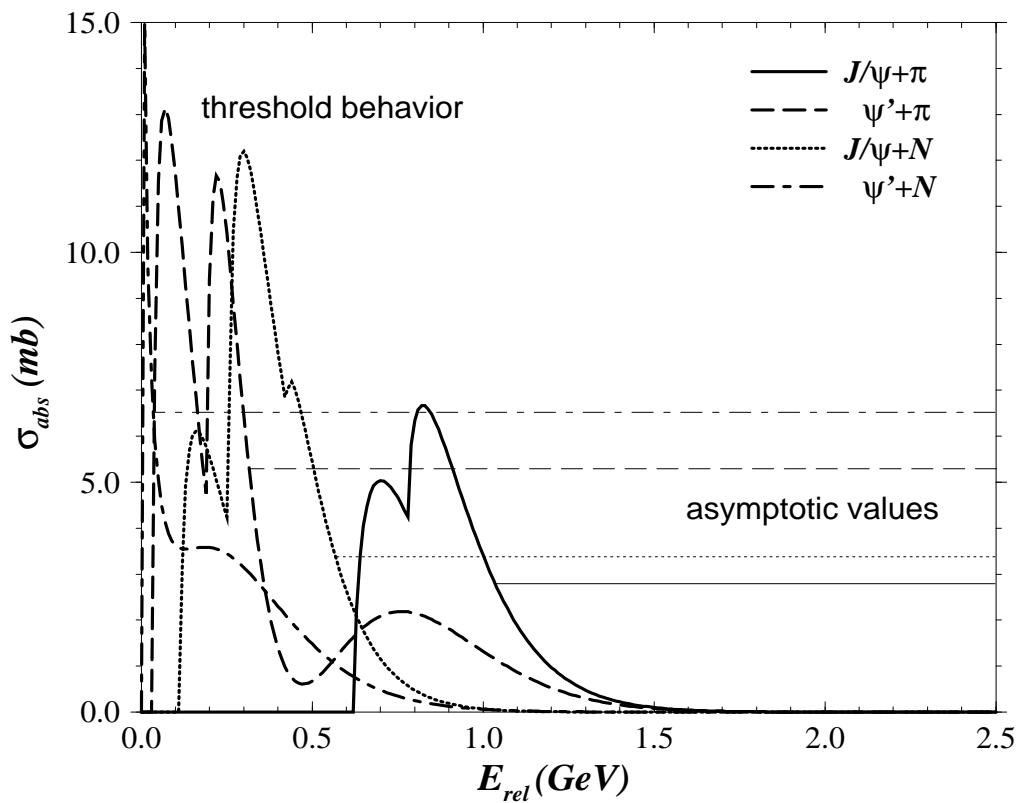


Fig. 1. Cross sections for the absorption of J/ψ and ψ' mesons by pions and nucleons near the reaction threshold and at high energies.

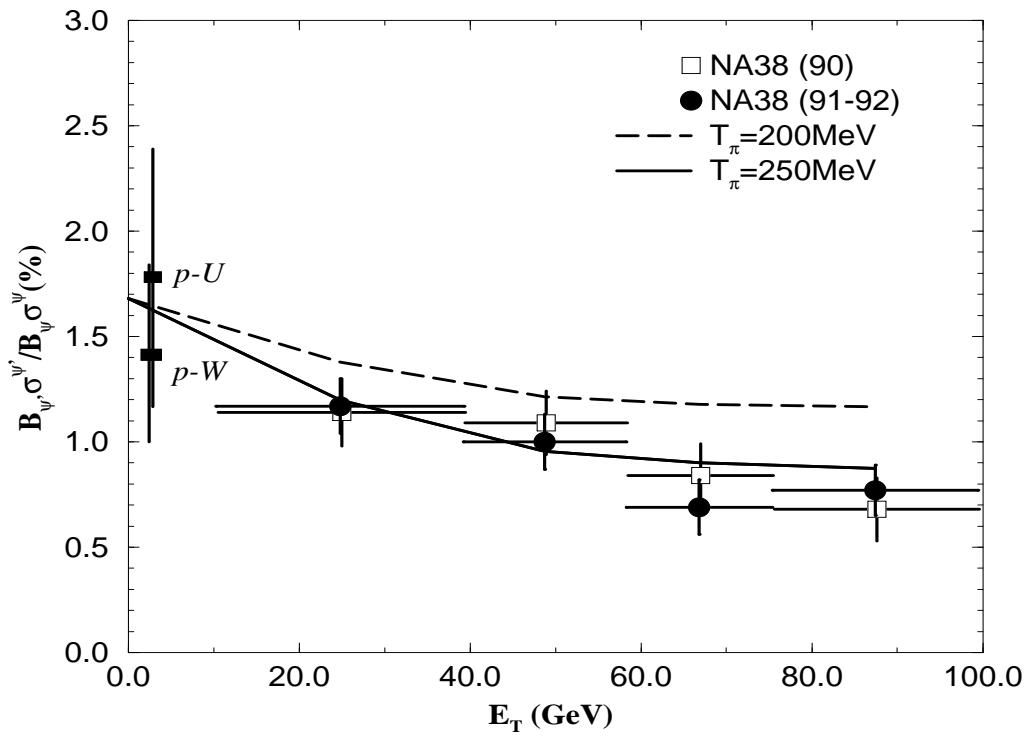


Fig. 2. ψ'/ψ ratio in S-U collisions at 200 GeV A. Curves are shown for two pion gas temperatures.